Establishing coal-water-wind (solar) energy comprehensive green energy mining system by using mine water
WeiBo Sun, Yan Wang, LeiMing Zhang, YanDa Liu and Xin Wang

ABSTRACT
Coal mining will damage water resources, based on the analysis of mine water resources in the western region of China. Using mine water as the medium, a coal-water-wind (solar) energy comprehensive green energy exploitation system is established. Mine water is stored in underground spaces formed by mining, and mine water purification is achieved by fractured rock and goaf. Using multistage underground reservoirs, through pumping to store energy, the unstable solar and wind energy is converted into a stable output power. The possibility of using the mine water as a medium to use the clean energy, and the prospect of the utilization of mine water resources in the future, is discussed.

Key words: coal mine, mine water, pumped storage, solar energy, underground reservoir, wind energy

INTRODUCTION
China’s coal resource geological reserves rank the third in the world. Since the beginning of the 21st century, China has become the largest coal producer in the world and water inrush in China is one of the most serious in the world (Qiang 2014). The coal reserves threatened by water account for about 27% of the proven reserves (Wu & Li 2009). The western region of China is fragile and the coal reserves account for 71.6% of the country’s coal reserves, and its water resources account for only 3.9% of the country’s water resources, which makes it a severe water shortage area. With the westward shift of China’s coal development strategy, the proportion of coal output in the western region will also increase. The contradiction between the development of coal and the shortage of water resources is more prominent. In the process of coal mining, the downhole dust suppression and the cooling of the machines and pumps all need water consumption. In order to ensure the safety of mining, a large amount of mine water is discharged (He et al. 2008). According to the water quota of coal production, the average water consumption is about 0.5 m³/t, that is, the water consumption of raw coal is about 1.8 × 10⁹ m³/a in China (Yu et al. 2015). More importantly, coal mining will destroy underground aquifers and produce a great deal of mine water. According to statistics, the average water consumption of coal mining in China is about 2.0 m³/t (Zhijun et al. 2013). The production of mine water is considered to be a hazard, and a considerable part of the mine water is discharged to the surface. Because there is no space to store the mine water on the ground, except for a small amount of underground water and the surrounding area near the mine, most of the mine water evaporates, not only polluting the environment, but also making the problem of water shortage more and more serious. At present, about 8 × 10⁹ m³/a (He & Li 2010; Qiang & Zhiqiang 2010; Yu 2010) of mine water is produced in China’s coal mines, and the loss is about 6 × 10⁹ m³/a. The loss of mine water resources is equivalent to 60% of the annual water shortage of industry
and for life in China (Wu & Li 2009). The western part of China belongs to the arid monsoon climate. The annual rainfall is less than 450 mm, but the evaporation is about six times the rainfall. The serious shortage of surface and groundwater supply makes this more prominent (Zhou et al. 2006). Therefore, how to realize coal exploitation, protection of water resources and coordinated use of more clean energy, such as wind energy and solar energy, and how to protect the environment and make good use of water resources and realize sustainable ecological green coal mining technology is very important to the process of western development in China.

**METHODS**

In Western China, the climate is dry and the water resources are short, but it has rich coal resources and clean wind energy and solar energy. If the mine water can be effectively treated and utilized, the application of mine water to the production and life will effectively improve the current situation of water shortage in the western region.

In the forecast of China’s future energy demand structure, the proportion of renewable clean energy is gradually increasing, and by 2050, accounts for almost half of the total energy demand (Xie et al. 2015). The growth of wind energy and solar energy is the most obvious. However, solar energy and wind energy are random, intermittent, and fluctuating, thus cannot maintain stable constant supply. Because of its poor power generation stability and continuity, this will bring huge challenges to the real-time balance of the power system and to maintain safe and stable operation of the power grid after wind or solar power integration. At the same time, its operation mode is limited by the load demand of the power system. Therefore, the large-scale storage of surplus energy, energy storage and efficient power generation at the peak of electricity consumption become the key technology bottlenecks restricting the large-scale development of solar energy and wind energy. Conventional thermal power and nuclear power also need large-scale energy storage facilities for economic peak. The only thing that meets the demand now is the pumped storage power station.

The coal-water-wind (solar) energy comprehensive green energy mining system refers to when coal mining, without affecting the safety of coal mining, the mine water stored in the goaf, using the horizon elevation of the goaf, converting solar energy and wind energy into stable energy by using the method of pumped storage, establishes a green energy system for comprehensive application of mine water, solar energy, and wind energy (see Figure 1). Thus, the impact and destruction of coal mining are reduced on the ecological environment, producing the comprehensive development of coal, water, and wind (solar) energy, and achieving the goal of coordinated and sustainable development of the mining ecosystem.

**RESULTS AND DISCUSSION**

In order to make the coal-water-wind (solar) energy comprehensive green energy mining system run normally, stable mine water resources are the premise and guarantee. The research shows that in Western China, coal mining will destroy the Quaternary aquifers. In the early stage of coal mining, the pore water in the Quaternary system percolates to the underground, which is an important source of the early stage of the mine water. Geological exploration shows that there is a large amount of bedrock fissure water in the coal measures strata in the western region, which accounts for about 76% of the total underground water resources in the Ordos Basin (Dazhao 2015). This observation shows that the long-term seepage of the bedrock fissure water is the source of the long-term stability of the mine water. For example, in Daliuta coal mine, after 2005, the inflow is long-term stable at around 500 m³/h, providing water security for the follow-up utilization of mine water (Figure 2).

Underground reservoirs of coal mines refer to stored water in the void of the goaf formed by coal mining (Chen & Ju 2011). The safety coal pillar is joined together by an artificial dam, and the reservoir dam is formed (Dazhao 2015). Meanwhile, mine water storage facilities and water intake facilities are built in the right position. Mine water of the underground coal mine reservoir is purified by the goaf rock mass and fracture of rock mass. This technology breaks through the original ‘interception method’ water
conservation concept, and adopts the idea of ‘guiding and storing’, that is, the method of dredging the mine water to the underground goaf for storage and utilization. This method avoids the efflux of evaporation loss, and the high cost of surface water treatment plant construction and operation (Figure 3).

For multilayer coal, a number of underground reservoirs can be set up, and the reservoir can be a water diversion structure. The reservoir should establish the monitoring and control system of water level and water quantity, realizing the water transfer between the reservoirs, ensuring the

Figure 1 | Coal-water-wind (solar) energy comprehensive green energy mining system.

Figure 2 | Statistics of water inflow in Daliuta coal mine.

Figure 3 | Underground reservoir of coal mine.
safety of the reservoir. The location of the same level coal reservoir is selected at the bottom of the coal seam floor; there are no bad geological conditions around the reservoir, the permeability of the coal bed floor is low, and the water supply is stable. The location of the lower coal reservoir should not only satisfy the location criteria of the reservoir of upper coal, but also ensure the safety of the reservoir of upper coal. Thus, the horizontal safety distance between the lower coal reservoir and the reservoir of upper coal must be determined according to the variation law of the overburden stress field and the fissure field in the storehouse construction (Figure 4).

The water quantity between the multilevel reservoirs can be adjusted. The water transfer technology between the reservoirs includes the water transfer between the same layer of coal and the different layers of the underground reservoir. When the coal is mined, the corresponding supply and drainage pipeline system is built, upgrading and reforming the original underground water supply and drainage pipeline system, resulting in the interconnectedness of the same layer of underground reservoir. The interlayer water system of the underground reservoir is based on water, and are connected to each other through a large diameter borehole; interlayer reservoirs are interconnected through large diameter boreholes. Through monitoring and controlling the water level and water of each reservoir, water transfer between the reservoirs can be realized to ensure the safety of the reservoir (Figure 5).

There are many pollutants in mine water, so, mine water cannot be used directly for power generation. The adjacent coal seam is sandstone. Due to coal mining, coal seams overlying rock will collapse. When mine water is transported in
the underground reservoir, mine water and caving rock will make a solid–liquid couple, and the caving rock will filter mine water through filtration adsorption and ion exchange, and thus purify mine water. The establishment of an underground experimental system (Figure 6) shows that this process can effectively reduce the concentration of pollutants, such as suspended matter, calcium ion, and COD (chemical oxygen demand) in mine water. In order to enhance the filtration capacity, the fracture of rock mass can be expanded by carbon dioxide blasting in some rock strata, and the water permeability can be increased.

Taking the No. 2 underground reservoir of the Daliuta mine as an example, the content of suspended solids in the mine water before entering the reservoir is 164 mg/L, and the suspended matter content is less than 5 mg/L after filtration from the fractured rock mass of the mined out area and the carbon dioxide blasting fractured rock mass. Research shows that the mine water purification effect and rock mass in the empty area are closely related in migration speed and distance, and through the control of mine water intake, water points, the mine water and rock purification process can be controlled, improving the purification effect.

Coal mine underground reservoir technology has been used in Shendong mining area, completing a total of 32 underground reservoirs of coal mines. In Shendong mining area, the storage capacity of 31 million m³ is currently the world’s only coal mine underground reservoirs. The underground reservoir of coal mine supplies more than 95% of the water for the mining area, which ensures its sustainable development.

In the western region, clean energy, solar energy, and wind energy are abundant, but solar energy and wind energy are random, intermittent, and fluctuating, and cannot maintain stable constant supply. Owing to the large number of plains in the western region, it is difficult to find the natural high drop terrain conditions of surface pumped storage power stations. It is difficult to store solar energy and wind energy by surface pumped storage. Therefore, the underground pumped storage power generation facilities are a good choice. Especially, the construction of pumped storage power generation facilities in a mine or abandoned mine space can not only reduce the cost of building, but also have good economic, social, and environmental benefits, and shorten the period of building the reservoir. Many large and medium-sized coal mines and abandoned coal mines are distributed in the northeast, north, and northwest areas. If some coal mines or abandoned coal mines can be transformed into pumped storage power stations, they can provide the necessary conditions for the vigorous development of wind energy and solar energy, and make use of the existing underground space. The improved underground space increases stability while avoiding possible surface subsidence and collapse, and subsequent problems of water pollution and air pollution. The principle of drop type underground pumped storage power generation is consistent with the principle of conventional pumped storage (Lin et al. 2017). The difference is that the water storage facilities are placed underground, such as abandoned coal mines or metal mines in roadways and mined out areas (Figure 7). Compared with conventional pumped storage facilities, the water storage space already exists, and only requires the corresponding transformation, so does not consume the land resources of the surface and damage the environment of the earth's surface.

![Figure 6](https://www.ijccc.org/jwc/article-pdf/9/2/331/244042/jwc0090331.pdf)
Table 1 provides a forecast of the energy storage capacity of coal mines in China, and the statistics of coal mines that have been discarded and those running at present shown. It can be seen that the power generation capacity of the waste coal mines and mine reservoirs is amazing. The energy consumption of the waste coal mines is about 1.2 times that of the whole year in 2016. This new technology will open up new ways for reusing waste mines in China, renewable energy utilization and electric power storage, mining area ecological protection, and coal mining in Western China.

Taking the underground reservoir in Shendong mining area as an example, such as building a pumped storage system, the surrounding surplus solar and wind energy in the pumped storage system can store $1 \times 10^4$ MW·h. It can provide enough power for the surrounding areas, and also reduce the value of thermal power, so as to reduce coal mining and carbon dioxide emissions and further improve the surrounding ecological environment.

CONCLUSION

Utilizing the resources of mine water, establishing the theory and technology of coal-water-wind (solar) energy multi-resource collaborative development is a new way of mine water resource utilization, and it is a new attempt for the modern coal industry to achieve harmonious and sustainable development. Research shows the following:

- According to the size of the water inflow of the mine and the condition of the coal seam, the underground reservoir system with stable storage capacity is established, which can effectively store the mine water resources.
- The use of the caving rock and rock mass in the goaf to clean the mine water can effectively reduce the pollutants in the mine water.
- By using the height difference of multi-level underground reservoirs, the unstable wind energy and solar energy and other clean energy can be transformed into a stable electric energy, so as to achieve the coordinated development of coal-water-wind (solar) energy.

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<thead>
<tr>
<th>Water storage position</th>
<th>Volume of water storage (m$^3$)</th>
<th>Drop (m)</th>
<th>Peak flow rate (m$^3$/s)</th>
<th>Power generation power (MW)</th>
<th>Storage energy (MW·h)</th>
</tr>
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<tbody>
<tr>
<td>Ruhr-waste coal mine in Germany</td>
<td>60</td>
<td>580</td>
<td>40</td>
<td>215</td>
<td>880</td>
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<tr>
<td>All abandoned coal mines in China</td>
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<td>300</td>
<td>40</td>
<td>120</td>
<td>$7.25 \times 10^6$</td>
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<tr>
<td>Existing large coal mines in China</td>
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<td>400</td>
<td>45</td>
<td>180</td>
<td>$6.11 \times 10^6$</td>
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REFERENCES


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